

Rainfall Observations by the Airborne Dual-Frequency Precipitation Radar During CAMEX-4

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ABSTRACT

The 2nd Generation Precipitation Radar is a new design for a dual-frequency (13.4 and 35.6 GHz) spaceborne precipitation radar. An airborne PR-2 simulator has been developed to demonstrate key technologies. This airborne system was flown on the NASA DC-8 aircraft during the 4th Convection and Moisture Experiment in 2001. Data were acquired in Tropical Storms Chantal and Gabrielle, Hurricane Humberto, and in several more localized convective systems. The authors discuss the design of the PR-2 airborne radar and show observations from CAMEX-4. Overall, the observations validated the design of PR-2 and provide an extensive data set for scientific analyses.

I. INTRODUCTION

The launch of the Tropical Rainfall Measuring Mission (TRMM) satellite [1] in late 1997 has made a great stride towards understanding the global structure of precipitation. The Precipitation Radar (PR) aboard the satellite is the first-ever spaceborne radar dedicated to three-dimensional, global precipitation measurements over the tropics and the subtropics.

Because of the TRMM success, a follow-on mission, called the Global Precipitation Mission (GPM), is currently being planned to extend the TRMM's instrument capability in such a way to fully address the key science questions from microphysical to climatic time scale. The baseline GPM configuration includes a high-resolution, wide-swath scanning, dual-frequency radar. A second generation dual-frequency precipitation radar (PR-2), which could be used for GPM or follow-ons to GPM has been designed [2]. This system includes digital, real-time pulse compression, extremely compact RF electronics, and a large deployable dual-frequency cylindrical parabolic antenna subsystem. The antenna is fed by a planar active array for electronic beam scanning.

To demonstrate many of the key PR-2 technologies and designs, an airborne version of PR-2 has been developed. In the next section we describe the design of this airborne PR-2. In the following section we discuss its operation on the NASA DC-8 aircraft in the Fourth Convection and Moisture Experiment (CAMEX-4) in 2001.

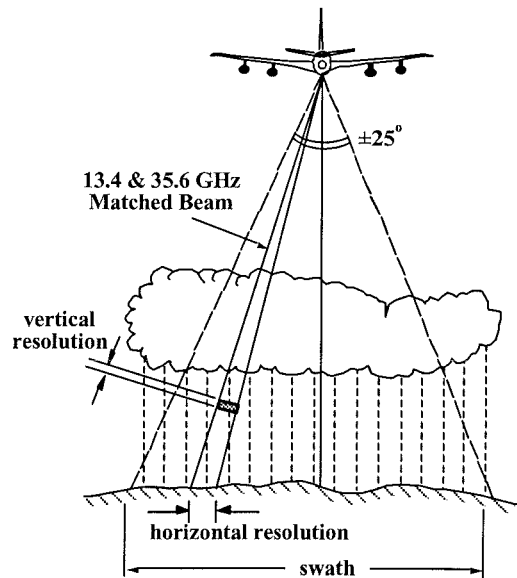


Fig.1 .PR-2 operational geometry on the NASA DC-8 aircraft. Antenna is scanned in cross-track plane.

II. SYSTEM CONCEPT

The airborne PR-2 system includes a real-time pulse compression processor, a fully-functional control and timing unit, and a very compact LO/IF module, all of which could be used in spaceborne applications. The cylindrical reflector antenna and linear feed array for the spaceborne PR-2 have been replaced by traveling wave tube amplifiers (TWTAs), front-end electronics, and an offset parabolic reflector antenna with mechanical scanning. The airborne PR-2 operational geometry is shown in Fig. 1; it looks downward and scans its beam across-track, with each scan beginning at 25 degrees to the left of nadir and ending at 25 degrees to the right. It uses the same scanning antenna reflector as that used for the Airborne Rain Mapping Radar (ARMAR) [3]; it consists of a 0.4 m offset reflector antenna with a mechanically scanned flat plate. For PR-2 the 13.8-GHz antenna feed has been replaced by a dual-frequency feed (13.4 and 35.6 GHz) and the aperture at 35.6 GHz is under-illuminated to provide matched beams at the two frequencies. This choice results in poor Doppler accuracy at

Ka-band, but is needed for rain retrieval. Table 1 shows the parameters for the airborne PR-2.

The RF circuitry can be divided into two categories: circuits operating at frequencies of less than 1.5 GHz and circuits operating at frequencies above 1.5 GHz. The lower frequency (below 1.5 GHz) circuitry is all contained in a single unit, the local oscillator / intermediate frequency (LO/IF) module. This unit converts transmit chirp signals from 15 MHz up to 1405 MHz and downconverts received IF signals from 1405 MHz to 5 MHz. The unit contains both upconversion channels and all four receive channels and fits into the equivalent of a double wide 6U-VME card.

The RF front-end electronics are unique to the airborne PR-2 design and consist of five units: one local oscillator / up converter (LO/U) unit, two TWTAs and two waveguide front end (WGFE) units. In the DC-8 installation, the two TWTAs are stacked vertically in a standard rack with the LO/U in between them and the two WGFEs are mounted on top of the antenna pressure box, near the antenna feed.

The digital electronics consists of a control and timing unit (CTU), an arbitrary waveform generator (AWG), and a data processor. The CTU generates the pulse timing and all other timing signals. It also provides control signals to RF. The AWG is loaded with a digital version of the linear FM chirp that is to be transmitted. The data processor is based on FPGA technology. It performs pulse compression and averaging in real-time. Unlike ARMAR, which used a frequency domain pulse compression algorithm in post-processing, the pulse compression scheme in PR-2 is based on real-time filtering in the time domain. The 4 MHz bandwidth received signals are sampled at 20 MHz, then digitally downconverted to complex samples, resulting in I and Q samples at 5 MHz rate. The data processor also includes pulse-pair Doppler processing. The output of the processor is the lag-0 (power) and lag-1 (complex Doppler data) for the co- and cross-polarized channels at each frequency. A VME-based workstation runs the radar, including ingesting and saving the processed data. Following calibration on the ground, the PR-2 data are stored in a HDF format similar to that from the TRMM PR.

Table 1. Airborne PR-2 Parameters

Frequency	13.4 GHz	35.6 GHz
Polarization	HH,HV	HH, HV
Antenna diameter	0.4 m	0.14 m
Beamwidth	3.8 deg	4.8 deg
Antenna gain	34 dBi	33 dBi
Antenna sidelobe	-30 dB	-30 dB
Polarization isolation	-25 dB	-25 dB
Peak power	200 W	100 W
Bandwidth	4 MHz	4 MHz
Pulse width	10-40 μ s	10-40 μ s
PRF	5 kHz	5 kHz

Vertical resolution	37 m	37 m
Horizontal resolution	800 m	800 m
Ground Swath	10 km	10 km
Noise-equiv. Ze (10 km range)	5 dBZ	5 dBZ
Doppler precision	0.4 m/s	>1 m/s

III. RADAR OBSERVATIONS IN CAMEX-4

PR-2 was completed in the summer of 2001 and was then deployed to Florida to participate in CAMEX-4, which has the prime objective of using advanced remote sensing techniques in hurricanes. As a result, data that is useful for both evaluation of PR-2 performance and for scientific studies were obtained, although the Ka-band data was very limited due to problems with the off-the-shelf Ka-band TWTA. Fig. 2 shows the observed minimum detectable reflectivity Z_f or PR-2 at both frequencies. This was derived from clear-air observations. The values for both Ku-band and Ka-band are below 5 dBZ at 10 km range from the radar. The surface return, along with pulse compression sidelobes can be seen at approximately 12 km range. The pulse compression sidelobes, rather than thermal noise, limit the performance near the surface. Achieving such low pulse compression sidelobes required careful design of the transmit waveform and control of gain and phase errors.

Also of concern is the calibration of the radar. Calibration can be verified using observations of the ocean surface. This technique has been used previously with ARMAR [3], since the ocean backscatter near nadir is well known, especially near 10 degrees incidence, where sensitivity to

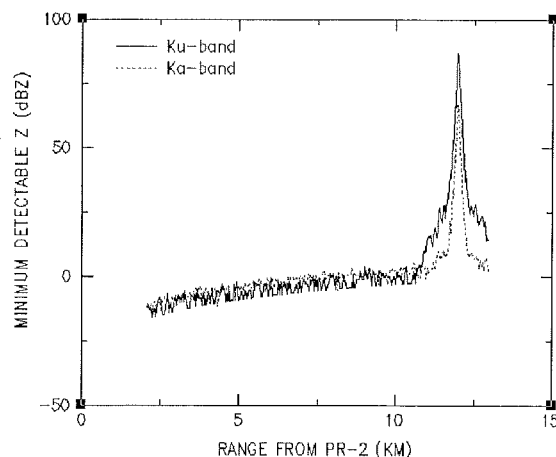


Fig. 2. Observed minimum detectable reflectivity versus range.

wind speed is a minimum. Ocean backscatter at Ka-band is much less well characterized, although models show similar behavior to Ku-band. At Ka-band the reflectivity in very light rain should be nearly identical to that at Ku-band, since Rayleigh scattering should apply at both frequencies.

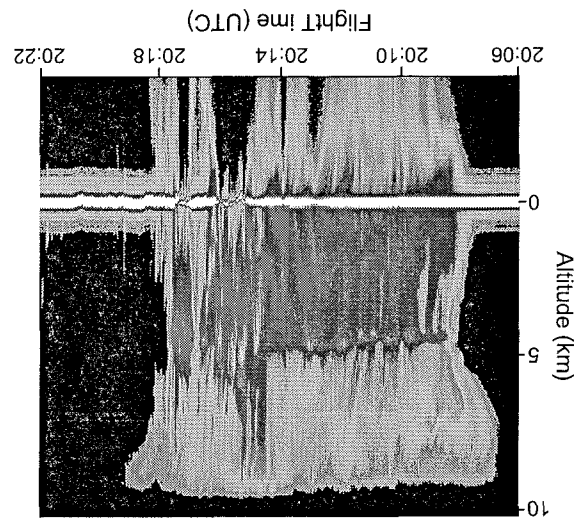
will be used in rain retrieval algorithm studies, as well as studies of tropical cyclones.

ACKNOWLEDGMENTS

The research described in this paper was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Observations of the ocean surface with PR-2 show a cross section near 7 dB, which is close to previous measurements. The Ka-band data have reflectivities within about 1 dB of the Ku-band reflectivities in light rain.

Fig.3 . PR-2 nadir reflectivity in Tropical Storm Chantal.

PR-2 collected data on all CAMEX-4 flights. Ku-band data are available for a II flights, while some Ka-band data exist on all but the first two flights. Data acquired include the reflectivity, linear depolarization ratio, and Doppler at Ku-band and the Ka-band reflectivity. Fig. 3. shows a nadir Ku-band reflectivity profile from Tropical Storm Chantal. The horizontal axis is time and the vertical axis is altitude. Highest reflectivity areas are shown in purple. Fig. 4 shows reflectivity profiles in a stratiform rain area within Tropical Storm Gabrielle. The solid line is Ku-band, while the dashed is Ka-band. The much larger attenuation at Ka-band is obvious. We have applied both single frequency and dual-frequency methods to retrieving rainfall and have found similar rainfall profiles. The advantage of the dual-frequency method is that the profile of the median drop size can also be retrieved. Dual-frequency data were also acquired in Hurricane Humberto on three separate flights.

IV. SUMMARY

The PR-2 airborne radar was described. This system includes several innovations, including real-time pulse compression. Some preliminary results of data analysis from CAMEX-4 were then presented. Overall, the performance appears to meet requirements. In spite of problems with an off-the-shelf TWTAs, several useful legs of Ka-band data were acquired in tropical cyclones and convective systems. A complete set of Ku-band data were also acquired. These

Fig.4 . P R-2 reflectivity profiles in Tropical Storm Gabrielle.

